2004

Effect of Various Levels of Forage and Form of Diet on Rumen Development and Growth in Calves

Josie Coverdale
Iowa State University

Howard Tyler
Iowa State University

James D. Quigley III
American Protein Corporation, Inc.

Jennifer Brumm
Northeast Iowa Community-Based Dairy Foundation

Effect of Various Levels of Forage and Form of Diet on Rumen Development and Growth in Calves

A.S. Leaflet 1909

Josie Coverdale, graduate research assistant,
Howard Tyler, associate professor of Animal Science,
J.D. Quigley, III, American Protein Corporation, Inc. Ames
and Jennifer Brumm, Northeast Iowa Community-Based
Dairy Foundation, Calmar

Summary and Implications

The effect of form of starter grain (coarse versus ground) and inclusion of various levels of hay on rumen development was evaluated. Two experiments were conducted to determine the effect of form of diet and forage inclusion on intake, growth, feed efficiency and weaning age in dairy calves. Diets consisted of commercial coarse starter (C), ground starter (G), coarse starter with 7.5% bromegrass hay of consistent particle size (8 - 19 mm) (H1), and coarse starter with 15% hay (H2). In experiment 1, intake was held constant across treatments until weaning, when feed was offered ad libitum. Calves receiving H1 and H2 were heavier, had greater body weight gain and greater feed efficiency than calves receiving C. There were no differences in intake. Total volatile fatty acid (VFA) concentrations were higher and the proportion of acetate was lower for calves fed G versus C. In experiment 2, calves (n = 56) were offered diets on an ad libitum basis and weaned according to intake. There were no differences in body weight gain, average daily gain, feed efficiency and age at weaning with respect to treatment. Starter and total dry matter intake tended to be greater in calves fed H1 and H2 versus C.

Addition of controlled particle size hay to diets of young calves appears to favorably alter rumen environment resulting in increased intake and improved feed efficiency. Forage of a consistent particle size can be successfully utilized in starter rations of young calves.

Introduction

Intake of solid feed is vital to the calf for making the transition from a preruminant animal to a functioning ruminant. However, there is still much controversy concerning the composition of starter that should be fed to preruminant calves especially regarding the level of forage those diets should contain.

Forage consumption promotes muscular development of the rumen and stimulates rumination and flow of saliva into the rumen. However, it does not provide sufficient concentrations of rumen VFA, especially butyrate, required for optimal papillae development. Fermentation of concentrates provides the necessary butyrate to stimulate papillae development, but these feeds may promote keratinization of the papillae in calves and lambs.

The amount of roughage necessary in the diet of young calves is unclear. Trials investigating the use of forage in starter rations have yielded inconsistent results. Several investigators concluded that forage addition to the diet increases starter intake. However, others have seen a negative impact of forage addition on the consumption of starter rations.

Ration particle size influences the ruminal environment, volatile fatty acid production, and papillae structure and function. Diets that are chopped or ground to fine particle sizes decrease rumen pH and cellulolytic bacteria populations. This decrease in pH is caused by a lack of rumination and saliva flow into the rumen in calves and mature cows. Papillae of animals receiving small forage particles have increased keratinization. This decrease in active tissue results in decreased VFA absorption. Papillae begin to branch to compensate for the loss in metabolically active tissue.

Determining the proper level of forage, if any, to include in starter diets for optimal rumen development will benefit the producer greatly. Optimal rumen development will benefit the producer by shortening the length of time the calf requires milk replacer and allow early weaning of a mature ruminant calf. There are several advantages of early weaning when compared to the prolonged feeding of milk replacer. Labor is greatly reduced when calves are fed starter rations when compared to feeding milk replacer. Calves that are weaned earlier have fewer digestive problems. Determining the optimal level of forage necessary to develop the rumen properly will allow producers to wean younger calves that are more digestively mature. This should prevent the decline in intake and growth seen immediately after weaning. The objective of these studies was to determine the effect of form of diet and the inclusion of various levels of controlled particle size hay on rumen development, growth and health parameters in restricted-fed and ad libitum-fed calves.

Procedures

The institutional Animal Care and Use Committee approved all procedures used in these experiments.

Experiment 1

Calves and treatment

Holstein bull calves (n = 60) obtained from sale barns were utilized. The calves were approximately 2 to 5 d of age at arrival. Upon arrival (prior to initiation of the study), calves were randomly assigned to one of four treatment groups. On the day of arrival calves received one dose of a colostrum supplement (APC Lifeline Calf, Inc., Ames, IA). Calves were housed in individual hutches with wood

shavings for bedding. Water was offered for ad libitum consumption. Eight calves died during the investigation and 2 more were removed due to failure to consume adequate amounts of starter. Death losses did not differ according to treatment. Calves were vaccinated based on the protocol of the research facility.

Diets consisted of commercial coarse starter (**C**; Land O' Lakes, Ft. Dodge, IA), a starter with ground grain processed with a hammer mill and intact pellets (**G**), coarse starter with 7.5% bromegrass hay of consistent particle size (**H1**), and coarse starter with 15% grass hay of consistent particle size (**H2**). All diets were formulated to be isocaloric and isonitrogenous. The pellets in diets H1 and H2 were modified to account for the addition of hay (Table 1). Bromegrass hay used for the H1 and H2 diets was chopped and sorted by particle size using a Penn State Forage Separator. Hay particles were approximately 8 to 19 mm in length. Samples of diets were collected weekly and stored (-20°C) prior to analysis by a commercial laboratory (Iowa Testing Laboratory, Eagle Grove, IA) (Table 2).

A commercial milk replacer (12.5% DM, 20% CP, 20% EE, Merricks Inc., Middleton, WI) was offered at 10% of the initial body weight daily via bottles. Calves were offered milk replacer at this volume until weaned. Intake was held constant across treatments. Calves did not receive more starter until greater than 80% of them consumed all starter offered. Calves were offered 250 g of starter on d 2 – 24 of the trial, 350 g on d 25 – 47, and 450 g on d 48 – 50. Weaning occurred when all calves were consuming 450 g of starter on day 52 of the trial. Amounts of starter and milk replacer offered and refused were recorded daily. Daily fecal scores, administration of antibiotics and electrolytes were also noted. Fecal consistency was subjectively scored once daily using a scale of 1 = normal fecal consistency to 4 = severe scours. Jugular blood and rumen samples were obtained weekly (days 1, 8, 15, 22, 29, 36, 43, 50, 57, and 64 of the trial). Body weights were also measured weekly.

Collection of jugular blood samples and BHBA analysis

Blood samples were obtained approximately 3 hours after the a.m. meal. Blood was collected by jugular venipuncture in tubes containing ethylenediamine tetra-acetic acid (EDTA) (K_3) as an anticoagulant. After collection, plasma was harvested by centrifugation (3,000 x g for 15 min), placed in storage tubes and frozen (-20°C) until further analysis. Samples were then transported to the Iowa State University College of Veterinary Medicine Clinical Pathology Laboratory. Plasma samples were allowed to thaw and then concentrations of BHBA were determined spectrophotometrically at 340 nm.

Collection of rumen fluid and VFA analysis

Rumen samples were obtained via a stomach tube approximately 3 to 4 hours after the a.m. meal. Fluid was immediately frozen using dry ice and stored (-20°C) until later analysis. Samples were first prepared for VFA analysis by allowing them to thaw at room temperature. The sample tubes were then centrifuged at 3500 x g for 10 min. Samples containing large amounts of particulate matter were strained through 2 layers of cheesecloth. After centrifugation, samples were treated with 25% meta-phosphoric acid at a ratio of 5 parts rumen fluid to 1 part acid. Tubes were then covered, mixed, and allowed to stand for 30 minutes. Fluid was then centrifuged at 3500 x g for 10 minutes. The clear supernatant was removed and placed in 15 ml tubes and frozen (-20°C). Samples were than transported to North Carolina State University for VFA analysis.

Frozen supernatant thawed and centrifuged at 3500 x g for 10 min. A 1-ml aliquot of supernatant was added to 100 µl of internal standard in a gas chromatogram vial. The mixture was placed in the autoanalyzer. Rumen fluid VFA concentrations were determined by a Varion 3800 gas chromatograph (Varian Chromatography Systems, Walnut Creek, CA) using a Nikol fused silica capillary column (15 m; 0.53 mm i.d.; 0.5 µm film thickness; Supleco, Bellefonete, P.A.). Samples were run with a run time of 6 min. Peaks from samples were then compared to 4 standard solutions.

Statistical analysis

All data were analyzed using the mixed linear model (PROC MIXED) of SAS (1989). The covariance structure was modeled using an autoregression structure within animals and a random effect between animals. The model uses both RANDOM and REPEATED statements. This covariance structure specifies a random effect of differences between animals and creates a correlation structure within animals that decreases with increasing amount of time between measurements. Least squares means and standard errors were obtained according to treatment and week/day by treatment. The data were analyzed for 4 treatments (coarse = C, ground = G, coarse with 7.5% hay = H1, and coarse with 15% hay = H2). Main treatment effects were analyzed using calf within treatment as the error term. Orthogonal contrasts were made: G vs C, C vs H1 + H2, and H1 vs H2. Data were analyzed for the entire trial as well as preweaning and postweaning time periods to account for different methods of feeding. Insufficient rumen fluid was obtained from calves on days 8 and 15, therefore these data were omitted. Statistical significance was declared at probabilities < 0.05. Probability values between 0.05 and 0.15 were considered to be trends towards significance.

Experiment 2

Calves and treatments

Holstein (n = 48), Jersey (n = 3), Ayshire (n = 2), and Brown Swiss (n = 3) calves (total n = 56) were obtained from the Northeast Iowa Community College herd. At birth all calves received colostrum and injections of 5 cc Penicillin G Procaine and 4 cc Bo-Se vitamin E and selenium (Schering-Plough Animal Health, Union, NJ). Calves were alternately assigned to one of 4 treatment groups according to order of birth. Calves were housed in individual pens with wood shavings or straw for bedding. Water was offered on an ad libitum basis.

Diet composition (Table 1) and analysis (Table 2) was the same as used in experiment 1. A commercial milk replacer (12.5% DM, 22% CP, 20% Fat, Land O' Lakes, Ft. Dodge, IA) was offered at 10% of initial body weight daily via buckets until weaned. Weaning occurred when calves consumed 1.5% of initial body weight for 3 consecutive days (Greenwood et al., 1997b). All diets were offered from day one of age on an ad libitum basis.

Refusals of starter and milk replacer were recorded daily in addition to daily fecal scores. Daily administration of antibiotics and electrolytes were also recorded. Jugular blood was obtained and body weight was measured weekly. Calves were removed from the trial approximately 2 weeks after weaning.

Collection of jugular blood samples and BHBA analysis.

Blood samples were obtained and analyzed as in exp. 1.

Statistical analysis.

All data were analyzed as in exp.1.

Results and Discussion

Experiment 1

Intake

The intake of starter and total DM intake increased with age of the calves ($P < 0.01$). There was also a tendency for calves offered diets H1 and H2 to have higher DM intake over the entire trial ($P< 0.13$). Mean total DM intake was 0.96, 0.99, 1.04 and 1.00 kg (SE = 0.03) for calves fed C, G, H1 and H2, respectively. However, there were no other differences with respect to the intake of milk replacer, starter, or total DM intake due to the restricted amounts offered prior to weaning. Using forage of a consistent particle size appeared to reduce variation in intake observed in other investigations using long roughage. Several investigators have reported an increase in intake with addition of forage to the diet. However, others have found a negative correlation between intake of starter and hay in the ration.

Body weight gain and feed efficiency.

Throughout the course of the trial, there was a tendency for body weight to differ with treatment ($P < 0.15$) and age ($P < 0.01$) (Table 3). Mean bodyweight of the treatment groups did not differ on day 0 of the trial ($P > 0.15$). Average daily gain (ADG) also was affected by treatment ($P < 0.02$) and increased with the use of the coarse diet and the addition of hay (Table 3).

No differences were observed in bodyweight, ADG, and gain to feed ratio (G/F) with treatment prior to weaning ($P = 0.70$, P = 0.40, and $P = 0.33$ respectively). However, calves fed diets H1 and H2 tended to have greater body weights than calves fed C ($P < 0.07$) (Table 3). Differences were observed in bodyweight, ADG, and G/F with treatment ($P < 0.01$, $P < 0.01$, and $P < 0.01$ respectively) after weaning (Table 3). Calves fed diet C were heavier ($P < 0.03$), had greater ADG ($P < 0.01$), and had greater feed efficiency ($P < 0.01$) than calves fed G. Calves fed diet H1 and H2 were heavier ($P < 0.01$), had greater ADG ($P < 0.04$), and greater G/F ($P < 0.03$) than calves fed diet C. Calves fed diet H1 tended to have higher ADG ($P < 0.07$) and greater feed efficiency ($P < 0 .12$) than calves fed diet H2 (Table 3).

Calf health.

Daily fecal scores and days of electrolyte and antibiotic administration did not differ with treatment. Fecal scores were not different throughout the trial ($P = 0.64$), preweaning ($P = 0.66$), or postweaning ($P = 0.81$). Mean fecal scores were 1.38, 1.39, 1.39 and 1.41 (SE = 0.02) for calves fed C, G, H1 and H2, respectively. There was no administration of antibiotics or electrolytes after weaning. Prior to weaning there was no difference in antibiotic treatments ($P = 0.68$) or electrolyte administration ($P = 0.59$) with respect to treatment. Mean days given electrolytes were 0.003, 0.005, 0.008, 0.009 (SE = 0.003) for calves fed C, G, H1 and H2, respectively. Mean days treated with antibiotics were 0.03, 0.03, 0.02 and 0.04 (SE = 0.01) for calves fed C, G, H1 and H2, respectively.

Volatile fatty acid concentrations.

Total VFA concentrations (sum of acetate, propionate, isobutyrate, butyrate, isovalerate, and valerate) differed by treatment ($P < 0.01$) and age ($P < 0.01$) (Figure 1). Total VFA concentrations increased with increasing age of calves. Others have also observed this increase in total VFA concentrations with age. Total ruminal VFA concentrations observed in this investigation are higher than those previously recorded from rumen fluid sampled via stomach tube. This most likely reflects the time of sampling and difference in feeding methods between the preweaning and postweaning periods. Samples of rumen fluid were obtained approximately 3 hours after the offering of starter when VFA concentrations typically peak.

In particular, samples taken on week 8 have extremely high concentrations. This is most likely due to the change in feeding regimen. Calves were offered starter ad libitum after weaning and intake of solid feed increased greatly in the first week postweaning. Increased ruminal VFA concentrations after weaning have been reported in other investigations. This increase in feed intake may have caused the large increase in ruminal VFA concentrations. In addition, the restricted intake prior to weaning may have resulted in an immature rumen epithelium that was not capable of rapid VFA absorption. By week 9, total VFA concentrations decreased to levels more commonly observed. At this time ad libitum intake of starter was stable for most calves and the increased access to solid feed should have resulted in a more mature rumen epithelium capable of absorbing large quantities of VFA. Molar concentrations of individual VFA also increased at 8 weeks and returned to normal values at 9 weeks.

Total ruminal VFA concentrations were higher in calves fed G diet versus C ($P < 0.01$) and tended to be higher for calves fed H1 versus H2 ($P < 0.10$) (Figure 1). Molar concentrations of acetate also were greater in calves fed diet G than calves fed C ($P < 0.01$) (Table 4). Concentration of propionate also was greater in calves fed diet G versus C ($P < 0.01$) and diet H1 versus H2 ($P < 0.03$) (Table 4). Butyrate concentrations were greater in calves fed diet G than those fed C ($P < 0.01$) (Table 4). Concentrations of isovalerate were unaffected by treatment ($P = 0.50$). Calves fed diet G had higher concentration of valerate and isobutyrate than calves fed C ($P < 0.01$ and $P < 0.02$ respectively). Ratio of acetate to propionate tended to change with treatment ($P < 0.12$). Calves fed diet H2 had a higher ratio of acetate to propionate than calves fed H1 ($P < 0.03$).

Proportions of acetate, propionate, and valerate as a percent of total VFA tended to differ with treatment ($P < 0.09$, $P < 0.07$, and $P < 0.06$ respectively) (Table 4). Calves fed diet G tended to have a greater proportion of isobutyrate ($P < 0.09$), greater proportions of valerate ($P < 0.01$), and tended to have lower proportions of acetate ($P < 0.06$) than calves fed C. Calves fed diet C tended to have greater proportions of butyrate than calves fed H1 and H2 ($P < 0.10$). This is consistent with other reports of similar results with the inclusion of hay in the diet. Calves fed H1 had greater proportions of propionate ($P < 0.01$) and lower proportions of isovalerate ($P < 0.05$) than calves fed H2 (Table 4).

β-Hydroxybutyrate concentrations.

Plasma concentrations of β-hydroxybutyrate (BHBA) did not differ with treatment prior to or after weaning, or during the entire trial (Table 5). This is in contrast to some studies that observed a decrease in plasma BHBA as hay intake increased. However this trial used restricted amounts of grain and ad libitum access to long hay postweaning. Therefore, calves did not consume consistent amounts of hay. Plasma BHBA concentrations did increase with age of the calf regardless of treatment ($P < 0.01$). There were no significant differences throughout the entire trial ($P = 0.46$), as well as the preweaning ($P = 0.62$), or postweaning periods ($P = 0.36$).

Experiment 2

Intake.

Intake of milk replacer did not differ by treatment ($P = 0.60$). Intake of starter also did not differ by treatment over the entire trial ($P = 0.31$) or prior to weaning ($P = 0.73$) (Table 6). However, there was a tendency for starter intake to be greater for calves offered H1 and H2 versus C ($P < 0.11$) after weaning (Table 6). Intake of starter and dry matter increased with age ($P < 0.01$). Total DMI also did not differ by treatment over the entire trial ($P = 0.25$), but there was a tendency for calves receiving H1 and H2 to have a higher total dry matter intake than those offered C ($P < 0.15$) throughout the trial (Table 6). This is similar to data from experiment 1.

There was little variation in the intake of solid feed with respect to forage addition to the diet. This is in contrast to other investigations utilizing long roughage . The consistent particle size of the forage used in the dietary treatments in our study results in less variation in intake.

There was no difference in dry matter intake prior to weaning ($P = 0.84$) (Table 6). However, after weaning there was an effect of treatment on total intake ($P < 0.15$). Calves receiving diet C tended to consume more total dry matter than calves fed diet G ($P < 0.15$), indicating that form of diet impacts the intake of solid feed. Franklin et al. (2003) also observed an effect of form of diet on starter intake in calves. Their trial evaluated textured, ground and pelleted starters. The authors observed calves fed textured starter had greater intake and were weaned sooner than calves fed pelleted starter. However, this trial did not include forage in the dietary treatments.

Calves fed diets H1 and H2 tended to consume more total dry matter than those fed C ($P < 0.11$) postweaning (Table 6). This is similar to other investigations that have shown an increase in starter consumption with the addition of forage to the diet (Kincaid, 1980; Stobo et al., 1985; Thomas and Hinks, 1982). However, others have seen a negative impact of forage addition on the consumption of starter rations (Hibbs et al., 1956; Whitaker et al., 1957; Leibholz, 1975). In experiment 1 there was no difference in starter or total dry matter consumption postweaning. However, the calves in that trial had restricted intake of solid feed prior to weaning; this may have altered the consumption of feed postweaning.

*Body weight gain and feed efficiency***.**

Body weight gain increased with age of the calves ($P < 0.01$). However, there were no differences in body weight gain with respect to treatment throughout the entire trial ($P = 0.72$), preweaning ($P = 0.75$), or postweaning ($P = 0.68$) (Table 6). In experiment 1 we observed that calves fed diet C were heavier than those fed G, and calves receiving diet H1 and H2 were heavier than those receiving diet C postweaning.

Average daily gain also did not differ by treatment over the entire trial ($P = 0.76$), preweaning ($P = 0.73$), or postweaning ($P = 0.53$) (Table 6). Feed efficiency, expressed as a ratio of kilograms of gain per kilogram of feed, also was unaffected by treatment. Gain to feed ratios were not different for the entire trial ($P = 0.85$), for the period prior to weaning ($P = 0.91$), or for the period after weaning ($P = 0.69$) (Table 6). Experiment 1 resulted in higher ADG and G/F in calves fed diet C versus diet G. In our previous trial, calves fed diets H1 and H2 had higher ADG and G/F than those consuming C when intake was restricted, suggesting that the restricted intake may have promoted increased efficiency of feed utilization in calves fed those diets.

*Calf health***.**

Daily scour scores, electrolyte and antibiotic administration did not differ with treatment. Scour scores were not different throughout the trial (P = 0.62). Mean fecal scores were 1.39, 1.50, 1.42 and 1.43 (SE = 0.06) for calves fed C, G, H1 and H2, respectively. The administration of antibiotics or electrolytes was also unaffected by treatment (P = 0.70). Mean days given electrolytes or antibiotics were 0.06, 0.08, 0.06, 0.05 (SE = 0.02) for calves fed C, G, H1 and H2, respectively.

*Age at weaning***.**

Weaning occurred according to starter intake by individual calves. Mean age at weaning was 32.5, 30.7, 31.6 and 30.9 d for calves fed C, G, H1 and H2 respectively. Weaning age did not differ with treatment (P = 0.72). This indicates that there was little difference in dry matter consumption and minimal variation in intake among the treatments.

*β-Hydroxybutyrate concentrations***.**

Plasma concentrations of BHBA did not differ with respect to treatment (Table 7). However, the plasma concentrations did increase with age of the calf regardless of treatment (P < 0.01). Others have observed this increase in BHBA with age. There were no significant differences throughout the entire trial (P = 0.91), as well as the preweaning (P = 0.83), or postweaning periods (P = 0.97). This indicates that there was little differences in the rumen metabolism of butyrate by diet.

These trials illustrate that both form of diet offered and the addition of forage of a consistent particle size influence intake and growth in calves. Forage of a consistent particle size can be successfully utilized in starter rations for young calves. The form of diet offered also affects intake of solid feed. Addition of forage to the diet resulted in heavier calves, improved feed efficiency and greater dry matter intake. Increased feed efficiency and altered VFA production observed here were most likely were in response to an improved rumen environment. The addition of forage may be an economical feedstuff for inclusion in starter rations for young calves. Further work is needed to determine the long-term effects of forage-containing diets.

Table 1. Ingredients of dietary treatments (as fed basis).

Ingredient	Concentration in Diet[1], %			
	C	G	H1	H2
Grass hay	------	------	7.50	15.00
Steam rolled corn	31.85	------	32.05	31.96
Fine cracked corn	------	31.85	------	------
Whole oats	10.00	------	9.81	9.86
Ground oats	------	10.00	------	------
Molasses	8.00	8.00	8.00	8.00
Preservative	0.15	0.15	0.14	0.13
Mixer Pellet[2]	50.00	50.00	42.50	35.05
Soybean meal	41.00	41.00	55.50	69.00
Wheat middlings	33.00	33.00	15.00	8.10
Soybean hulls	10.00	10.00	10.00	2.30
Distillers dried grains	5.00	5.00	5.00	5.00
Choice white grease	------	------	3.50	4.30
Molasses	1.50	1.50	1.50	1.50
Microingredients	9.50	9.50	9.50	9.80

[1]C = rolled corn, whole oats, and intact pellets; G = rolled corn and whole oats processed with a hammermill and intact pellets; H1 = rolled corn, whole oats, modified intact pellets and 7.5% grass hay; H2 = rolled corn, whole oats, modified intact pellets and 15% grass hay

[2]Ingredients of mixer pellet listed as a percentage of the pellet mix (as fed basis)

Table 2. Composition of diets (DM basis).

Measurement	Diet[1]				Grass Hay[2]
	C	G	H1	H2	
DM (%)	90.50	90.50	90.30	89.60	86.23
CP (%)	22.76	22.60	23.51	21.73	15.56
EE (%)	3.51	3.12	4.74	5.50	------
NDF (%)	18.06	18.94	18.72	20.42	------
ADF (%)	7.43	10.54	10.74	10.71	37.57
Ca (%)	1.50	1.26	1.33	0.94	------
P (%)	0.66	0.59	0.58	0.49	------

[1]C = rolled corn, whole oats, and intact pellets; G = rolled corn and whole oats processed with a hammermill and intact pellets; H1 = rolled corn, whole oats, modified intact pellets and 7.5% grass hay; H2 = rolled corn, whole oats, modified intact pellets and 15% grass hay

[2]Grass hay = bromegrass hay used in diets H1 and H2

Table 3. Effect of form of diet and inclusion of forage on BW, ADG and G/F.

Item	Diet[1]				SE	Contrast *P* Values		
	C	G	H1	H2		C vs G	C vs H1 + H2	H1 vs H2
BW, kg								
Entire trial	47.8	48.7	51.9	50.7	1.4	NS	*	NS
Preweaning	44.9	46.3	48.5	47.6	1.4	NS	†	NS
Postweaning	59.2	58.7	65.6	63.3	1.6	*	**	NS
ADG, kg								
Entire trial	0.33	0.29	0.41	0.37	0.03	**	†	NS
Preweaning	0.17	0.17	0.18	0.18	0.03	NS	NS	NS
Postweaning	0.91	0.74	1.22	1.02	0.08	**	*	†
G/F[2], kg								
Entire trial	0.25	0.23	0.30	0.29	0.03	NS	NS	NS
Preweaning	0.17	0.18	0.20	0.20	0.04	NS	NS	NS
Postweaning	0.52	0.42	0.66	0.58	0.03	**	*	NS

[1]C = rolled corn, whole oats, and intact pellets; G = rolled corn and whole oats processed with a hammermill and intact pellets; H1 = rolled corn, whole oats, modified intact pellets and 7.5% grass hay; H2 = rolled corn, whole oats, modified intact pellets and 15% grass hay.
[2]Ratio of body weight gain (kg) to DM consumed (kg).
†P = 0.10 *P = 0.05 **P = 0.01

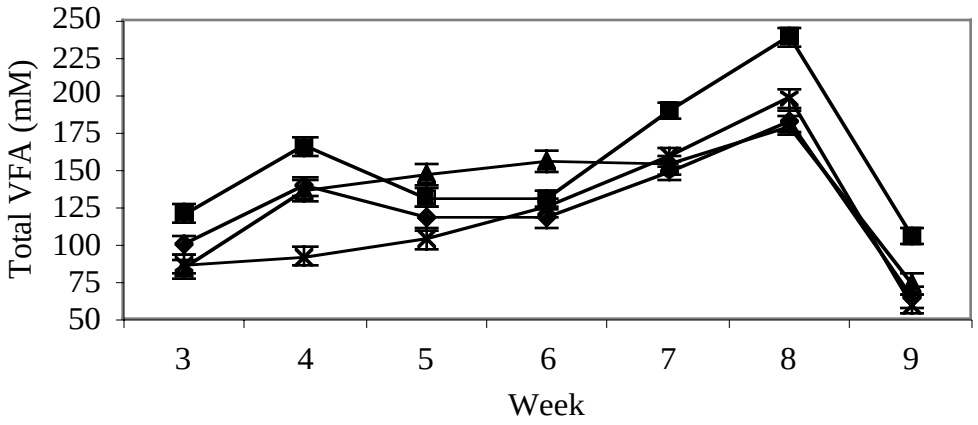

Figure 1. Total VFA concentrations in rumen fluid of calves fed various forms of diet (C ◆; G ■) and inclusions of forage (H1 ▲; H2 ×)

Table 4. Effect of form of diet and inclusion of forage on ruminal VFA concentrations.

Item	Diet [1]				SE	Contrast *P* Values		
	C	G	H1	H2		C vs G	C vs H1 + H2	H1 vs H2
Acetate, m*M*	44.8	55.1	47.4	43.8	2.2	**	NS	NS
Propionate, m*M*	30.8	40.2	34.6	28.4	1.9	**	NS	*
Isobutyrate, m*M*	0.4	0.6	0.5	0.5	0.2	*	NS	NS
Butyrate, m*M*	11.2	12.6	10.3	9.3	0.8	**	NS	NS
Isovalerate, m*M*	0.9	0.9	0.7	1.0	0.1	NS	NS	NS
Valerate, m*M*	3.4	5.2	3.5	3.0	0.5	**	NS	NS
A:P[2]	1.6	1.5	1.4	1.7	0.1	NS	NS	*
Acetate, %	40.7	39.7	40.8	42.4	0.8	†	NS	NS
Propionate, %	28.0	28.6	29.5	27.1	0.7	NS	NS	**
Isobutyrate, %	0.4	0.5	0.4	0.5	0.1	†	NS	NS
Butyrate, %	9.4	9.5	8.5	8.6	0.4	NS	†	NS
Isovalerate, %	0.7	0.7	0.6	0.9	0.1	NS	NS	†
Valerate, %	3.0	3.6	2.8	2.7	0.3	**	NS	NS

[1]C = rolled corn, whole oats, and intact pellets; G = rolled corn and whole oats processed with a hammermill and intact pellets; H1 = rolled corn, whole oats, modified intact pellets and 7.5% grass hay; H2 = rolled corn, whole oats, modified intact pellets and 15% grass hay.
[2]Ratio of acetate to propionate (m*M*).
†*P* = 0.10 **P* = 0.05 ***P* = 0.01

Table 5. Effect of form of diet and inclusion of forage on plasma BHBA.

Item	Diet[1]				SE	Contrast *P* Values		
	C	G	H1	H2		C vs G	C vs H1 + H2	H1 vs H2
BHBA, mmol/l								
Entire trial	0.16	0.17	0.16	0.15	0.01	NS	NS	NS
Preweaning	0.11	0.12	0.11	0.11	0.01	NS	NS	NS
Postweaning	0.35	0.37	0.33	0.32	0.03	NS	NS	NS

[1]C = rolled corn, whole oats, and intact pellets; G = rolled corn and whole oats processed with a hammermill and intact pellets; H1 = rolled corn, whole oats, modified intact pellets and 7.5% grass hay; H2 = rolled corn, whole oats, modified intact pellets and 15% grass hay.
†*P* = 0.10 **P* = 0.05 ***P* = 0.01

Table 6. Effect of form of diet and inclusion of forage on starter intake, DM intake, BW, ADG and G/F.

Item	Diet[1]				SE	Contrast *P* Values		
	C	G	H1	H2		C vs G	C vs H1 + H2	H1 vs H2
Starter intake, kg/d								
Entire trial	0.81	0.80	0.94	0.88	0.06	NS	NS	NS
Preweaning	0.26	0.27	0.30	0.29	0.05	NS	NS	NS
Postweaning	1.59	1.57	1.89	1.77	0.12	NS	†	NS
DM intake, kg/d								
Entire trial	1.03	1.02	1.14	1.08	0.05	NS	NS	NS
Preweaning	0.62	0.64	0.66	0.64	0.03	NS	NS	NS
Postweaning	1.66	1.62	1.91	1.79	0.10	NS	†	NS
BW, kg								
Entire trial	49.6	50.5	51.0	50.9	1.0	NS	NS	NS
Preweaning	43.5	44.5	44.5	44.4	0.8	NS	NS	NS
Postweaning	57.8	58.6	60.0	59.8	1.5	NS	NS	NS
ADG, kg								
Entire trial	0.52	0.53	0.56	0.56	0.04	NS	NS	NS
Preweaning	0.32	0.38	0.35	0.35	0.04	NS	NS	NS
Postweaning	0.78	0.72	0.85	0.82	0.07	NS	NS	NS
G/F[2], kg								
Entire trial	0.55	0.60	0.56	0.62	0.06	NS	NS	NS
Preweaning	0.59	0.68	0.62	0.65	0.09	NS	NS	NS
Postweaning	0.50	0.50	0.51	0.57	0.04	NS	NS	NS

[1]C = rolled corn, whole oats, and intact pellets; G = rolled corn and whole oats processed with a hammermill and intact pellets; H1 = rolled corn, whole oats, modified intact pellets and 7.5% grass hay; H2 = rolled corn, whole oats, modified intact pellets and 15% grass hay.
[2]Ratio of body weight gain (kg) to DM consumed (kg).
†*P* = 0.10 **P* = 0.05

Table 7. Effect of form of diet and inclusion of forage on plasma BHBA.

Item	Diet[1]				SE	Contrast *P* Values		
	C	G	H1	H2		C vs G	C vs H1 + H2	H1 vs H2
BHBA, mmol/l								
Entire trial	0.15	0.15	0.16	0.15	0.01	NS	NS	NS
Preweaning	0.07	0.07	0.08	0.08	0.01	NS	NS	NS
Postweaning	0.26	0.25	0.27	0.26	0.02	NS	NS	NS

[1]C = rolled corn, whole oats, and intact pellets; G = rolled corn and whole oats processed with a hammermill and intact pellets; H1 = rolled corn, whole oats, modified intact pellets and 7.5% grass hay; H2 = rolled corn, whole oats, modified intact pellets and 15% grass hay.
†*P* = 0.10 **P* = 0.05 ***P* = 0.01